ON THE BONE TISSUE RESPONSE TO SURFACE CHEMISTRY MODIFICATION OF TITANIUM IMPLANTS

Akademisk avhandling

som för avläggande av medicine doktorsexamen vid Göteborgs Universitet kommer att offentligen försvaras i föreläsningssalen på våning 5, Avdelningen för biomaterialvetenskap, Arvid Wallgrens Backe 20, fredagen den 30 september 2011, kl. 13.00 av

Byung-Soo Kang

Fakultesopponent: Professor Jinshan Pan. Division of Surface and Corrosion Science, Royal Institute of Technology at Stockholm, Sweden

UNIVERSITY OF GOTHENBURG

This thesis is based on the following original articles and manuscripts:

I. Byung-Soo Kang, Young-Taeg Sul, Se-Jung Oh, Hyun-Ju Lee, Tomas Albrektsson. XPS, AES and SEM analysis of recent dental implants. Acta Biomater, 2009 Jul; 5 (6): 2222-29

II. Byung-Soo Kang, Young-Taeg Sul, Yongsoo Jeong, Eungsun Byon, Jong-Kuk Kim, Suyeon Cho, Se-Jung Oh, Tomas Albrektsson. Metal plasma immersion ion implantation and deposition (MePIIID) on screw-shaped titanium implant: The effects of ion source, ion dose and acceleration voltage on surface chemistry and morphology. Med Eng Phys, 2011Jul;33(6):730-38

III. Young-Taeg Sul, Byung-Soo Kang, Carina Johansson, Heung-Sik Um, Chan-Jin Park, Tomas Albrektsson. The roles of surface chemistry and topography in the strength and rate of osseointegration of titanium implants in bone. J Biomed Mater Res A, 2009 Jun 15;89(4):942-50

IV. Byung-Soo Kang, Young-Taeg Sul, Carina Johansson, Se-Jung Oh, Hyun-Ju Lee, Tomas Albrektsson. The effect of calcium ion concentration on the bone response to oxidized titanium implants. Clin Oral Implants Res. 2011 [Epub ahead of print]

V. Byung-Soo Kang, Young-Taeg Sul, Carina Johansson, Hyung-Seop Kim, Tomas Albrektsson. Bone response to plasma immersion ion implantation and deposition of titanium implants with oxygen and magnesium. In Manuscript

Abstract

Background: Surface properties of titanium implants play an important role in osseointegration. From 1990, a lot of engineering techniques have been applied to dental implant productions for improving their clinical performance by changing surface properties. In particular, surface chemistry modification enhanced the strength and speed of implant integration in bone and has become a marketing trend in the production of new implants. However, it is not clearly understood why and how strongly surface chemistry modifications reinforce the osseointegration of titanium. Hence, it is required to investigate the bone response to surface chemistry modifications of titanium for a better understanding of the roles of surface chemistry on the osseointegration response.

Aims: The present thesis aims to investigate the bone response to chemistry-modified titanium implants. In particular, our purpose is to better understand the effect of surface chemistry on the osseointegration of titanium implants.

Materials and methods: Clinical implants, such as TiUnite, Osseotite, OsseoSpeed and SLA were analyzed. Surface engineering methods include plasma immersion ion implantation and deposition (PIIID) and micro arc oxidation (MAO). Using these techniques, Mg-, Ca- and O-incorporated titanium surfaces were prepared. Surface chemistry was analyzed by X-ray photoelectron spectroscopy and auger electron spectroscopy. For topographical analyses, we used scanning electron microscopy and optical interferometry. A total of 136 screw-shape implants were inserted into rabbit tibiae and the bone responses were evaluated after 3, 6 and 10 weeks of healing. Biomechanical strengths at the bone implant interface were measured by removal torque. Bone tissue responses were evaluated by quantifying bone metal contact, bone area and new bone formation from undecalcified cut and ground sections.

Results: Surface chemistry of the Osseotite, OsseoSpeed and SLA implants showed mainly TiO2, but surface topography varied with modification methods in use. In contrast, the TiUnite, prepared by an electrochemical oxidation technique, displayed porous structures as well as P-incorporation to the oxide layer. The PIIID process changed surface chemistry of titanium with plasma resources, but negligibly altered surface topography at the nanometer scale. The atom concentration of plasma ion increased with ion dose, but decreased with acceleration voltage. The MAO process not only incorporated Mg and Ca ions into titanium surfaces, but also produced microporous structures on the surface. Furthermore, the MAO process controlled the calcium concentration of titanium implants without significant change of chemical bonding states of Ca in titanium oxide. *In vivo* results showed that Mg-incorporated implants produced by the MAO technique increased the biomechanical bonding strength and osseointegration rate compared to non-incorporated titanium surfaces. Furthermore, Mg-incorporated implants produced by the PIIID demonstrated a significant increase of biomechanical bonding strength, bony contact and new bone formation compared to O-incorporated implants. Ca 4.2% and Ca 6.6% containing implants revealed no significant differences in biomechanical and histomorphometrical measurement outcomes in rabbit tibiae.

Conclusions: The surface chemistry and topography of clinical and experimental implants were greatly dependent of surface engineering methods. In particular, the PIIID technique modified surface chemistry by tailoring plasma source with negligible alternation of surface topography at the nanometer scale, thus enabling the investigation of the effect of bioactive implant surface chemistry on the bone response. Using the PIIID and MAO techniques, we found that the Mg-incorporation to titanium significantly enhanced the bone responses to implant surfaces. Furthermore, the Mg-incorporated titanium oxide chemistry played an important role on the strength and speed of osseointegration. Choosing one of two calcium concentrations had no significant influence on the bone response to the Ca-incorporated titanium implants.

Key words: Osseointegrated titanium implants, magnesium and calcium incorporated bioactive titanium oxide, metal plasma immersion ion implantation and deposition, micro arc oxidation, clinical implants, *in vivo* bone response

ISBN: 978-91-628-8325-6

Correspondence: Byung-Soo Kang, Department of Biomaterials, Institute of Clinical Sciences, Sahlgrenska Academy at University of Gothenburg, Box 412, Arvid WallgrensBacke 20, SE 413 46 Gothenburg, Sweden